269

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PROJECT APOLLO

APOLLO HIGH ALTITUDE ABORT STUDY
PERTAINING TO LOSS OF IMU REFERENCE ANGLES

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Summary

The results of a rotational three-degree-of-freedom study relating to loss of IMU reference angles during high altitude abort of the Apollo LEV are presented herein. Recommendations are made for preventing loss of attitude reference during abort, and additional studies are suggested.

Introduction

A rotational three-degree-of-freedom study without aerodynamics has been conducted to simulate aborts of the Apollo Command Module at high altitudes. The purpose of the study was to determine if the three gimbaled IMU would tumble during aborts, and, further, to suggest alternate methods to prevent loss of attitude reference during high altitude aborts.

Procedure

The analog study was conducted with the inertia characteristics of the LEV programed to vary with time. The gimbal angle rates were computed from the body axis rates using a pitch (θ), yaw (ψ), and roll (ϕ) rotation sequence. The on-off RCS system was employed for damping only and a deadband of two degrees per second was used. Primarily, the study was conducted with the kicker rocket operative and nominally alined. Variations investigated in the problem included: 1) ± 0.3 degree misalinement from nominal in the pitch sense for the escape rocket; 2) ± 0.3 degree misalinement from nominal in the roll sense for the escape rocket; 3) variations in initial roll rate only; 4) variations in initial pitch and yaw rates; 5) variations in combined initial roll, yaw, and pitch rates; and 6) the middle gimbal angle (ψ) and the outer gimbal angle (ϕ) displaced from nominal. Items (3) through (6) above included the nominal rocket alinement as well as the ± 0.3 degree misalinement angles in pitch and roll. Regarding item (6) above, at the present time only limiting abort rates are specified (40° in roll, 5° in pitch and yaw). Initial angles for ψ and ϕ were arbitrarily chosen as those that might result as a natural consequence of rolling.

The sequence of events during a high altitude abort was as follows: Escape and kicker rockets fire at zero time, the kicker rocket firing for 1.35 seconds and the escape rocket firing for 8 seconds (fixed characteristics of the LEV). Manual jettisoning of the tower was then assumed to occur two seconds after termination of the escape rocket thrust. Following this, the RCS system was activated to damp the vehicle's motion 3 seconds after the tower was jettisoned in accordance with present procedures. Alternatively, the RCS system was made to fire at zero time to damp the motion. Because of the jet logic employed and the center-of-gravity position with the tower attached, positive pitch rates are not damped while the tower is attached. It should be pointed out that both systems (systems A and B) were always operative when the RCS system was activated. It was conservatively assumed that tumbling of the IMU could occur if ψ, the middle gimbal angle, exceeded 75 degrees prior to 30 seconds after the initiation of abort.

Results

Results of the study, which should be considered preliminary in nature, are as follows:

a. Tumbling of the IMU can occur within the rocket misalinement angles specified and no initial rates imposed unless the RCS system is operative at zero time.

b. With an initial roll rate only imposed, roll rates of up to 30 deg/sec can be tolerated and tumbling will not occur for the specified misalinement angles provided the RCS system is operative at zero time.

c. For the combinations of pitch and yaw rates investigated, a pitch rate of 2.5 degrees per second and a yaw rate of 5 degrees per second are tolerable when the RCS system is operative at all times, whereas a combination of 5 degrees per second in pitch and 5 degrees per second in yaw is not. A roll rate of approximately 10 degrees per second can be tolerated in combination with the 2.5 degrees per second pitch rate and 5 degrees per second yaw rate.

d. With initial roll and yaw gimbal angles at zero time corresponding to a 90 degree roll about the X-body axis, tumbling occurred. Indications were that for a 30° roll angle about the X-body axis, tumbling probably would not occur.

e. Time histories of body rates indicate that a maximum resultant rate of about 1 rad/sec is possible when rather severe initial conditions are imposed. Further, after tower jettison and activation of the jets, the high rates damp to the deadband values in about 5 seconds. Two representative cases wherein tumbling of the IMU did and did not occur are shown as figures 1 and 2.

Conclusions

Based upon the results of the limited investigation reported herein, it appears that the IMU can provide a reference after abort provided:

1) the RCS system is operative at zero time; 2) initial pitch, yaw, and roll rates are limited to approximately 2.5 degrees per second, 5 degrees per second, and 10 degrees per second, respectively; and 3) the initial roll angle about an X-body axis is limited to about 30 degrees or less. In addition if a 90% probability on misalinement angles were to be considered adequate (assumed to be 0.165 degrees) higher rates probably can be tolerated prior to abort. Further, although not investigated, jettisoning of the tower while the escape rocket is still thrusting may reduce the possibility of losing attitude reference after LEV abort at high altitudes.

Recommendations

The following recommendations are made based on the results of the present study:

1. The consequences of activating the RCS system at zero time following LEV abort should be investigated for all altitudes.

2. Studies should be initiated to consider the feasibility of lowering the abort rate limits.

3. Studies should be initiated to consider the feasibility of manually jettisoning the tower during the firing of the escape rocket.

4. An expanded study should be initiated to investigate aerodynamic effects at high altitudes. The effects of deactivating the kicker rocket which is presently being considered should also be included.

FIGURE 1. - Time history of vehicle motion after abort with $\Delta\epsilon = 0.3^\circ$ laterally (right roll sense). Initial rates and angles are equivalent to zero. RCS activated 13 seconds after initiation of abort. Note that IMU tumbles.

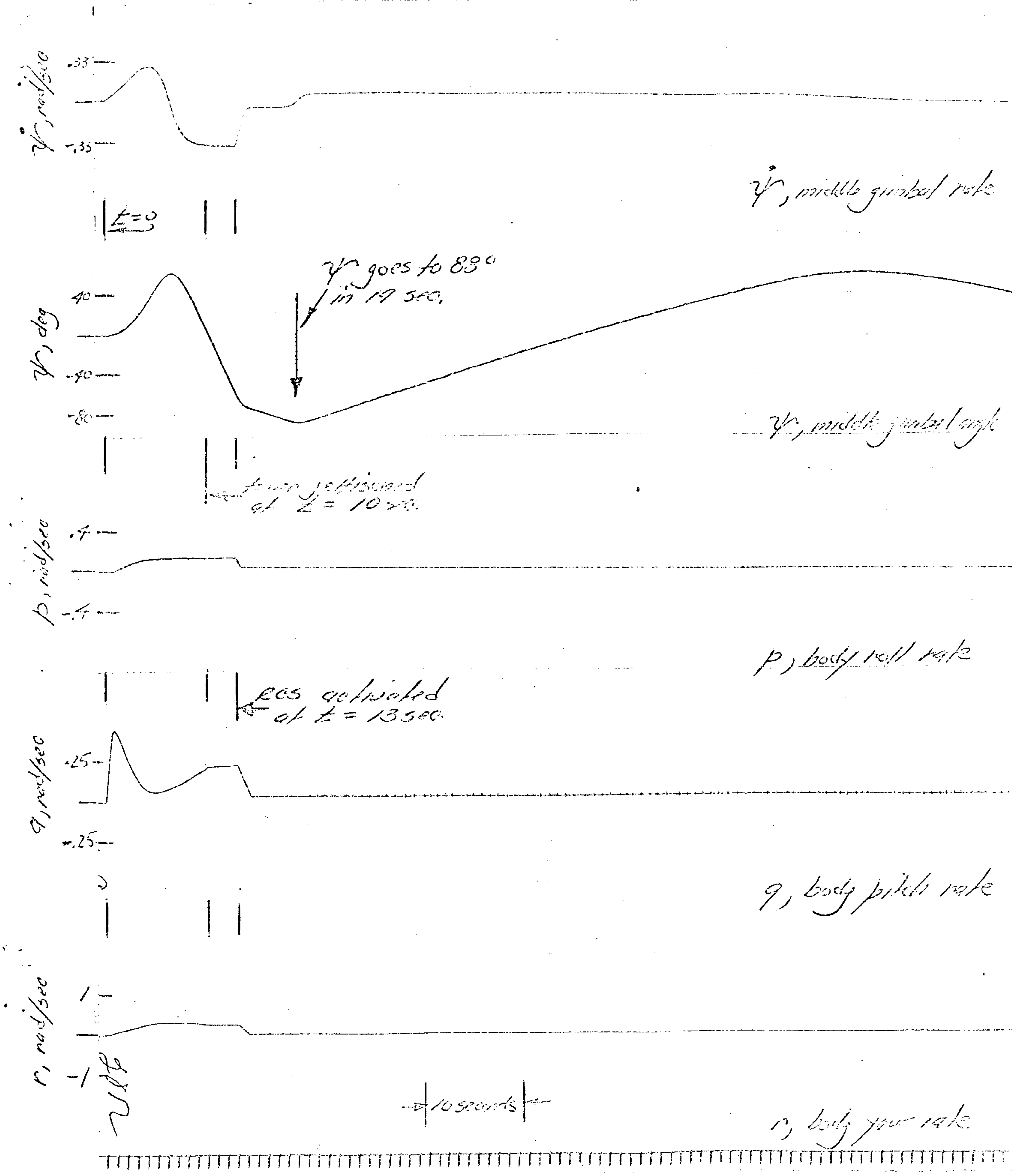

FIGURE 2. - Time history of vehicle motion after abort with nominal escape rocket alinement and initial conditions as follows: p=40°/sec, q=+5°/sec, r=+5°/sec. RCS activated 13 seconds after initiation of abort. Note that IMU does not tumble.